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3.2.2 Stream and river crossings

Stream and river crossings require the designer to consider the waterway in detail and, in some cases, obtain permits for the bridge. The topics listed below are to be considered in design of bridges over streams and rivers and are discussed in subarticles that follow.

- Hydrology
- Hydraulics
- Backwater
- Freeboard
- Roadgrade overflow
- Streambank Protection
- Scour

As a general rule, the design discharge for rural structures on Iowa's primary highway system is the 50-year flood. For bridge locations where the upstream flood damage potential is high or where the site is located in a detailed Flood Insurance Study (FIS) area, the 100-year flood should be the design discharge. When a project is located in a detailed FIS area, the published peak discharges and flood elevations are used for design. The average velocities (Q/A) through a bridge waterway opening typically should range between 6 and 8 feet/second (1.8 and 2.4 m/s) for the design discharge. The designer should calculate the following discharges for each bridge.

- Q_2 - for Corps of Engineers Section 404 permit information regarding quantity of fill (usually revetment) in cubic yards/running foot (cubic meters/running meter)
- Q_{50} - to determine velocity through bridge opening, backwater, and freeboard to the low superstructure elevation
- Q_{100} - to determine design scour and backwater and velocities through the bridge opening
- Q_{500} or $Q_{Overtopping}$ - to determine check (maximum) scour

3.2.2.1 Hydrology

Reliable estimates of flood-frequency discharges are essential for the economical planning and safe design of bridges and other structures located over streams. Hydrology for bridges should include the following peak discharges for design: Q_2, Q_{50}, Q_{100} and Q_{500} or $Q_{overtopping}$. In special cases the designer may need to determine additional discharges for the project.

The designer has several methods for determining estimated discharges, which are listed below.

- **Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS)**

  Many cities and counties in Iowa have detailed FISs. Typically, a community with an FIS has adopted regulations that prohibit increasing the 100 year flood elevation or encroaching upon a regulated floodway. The discharges and flood elevations in an FIS are usually legally binding and are used by the Iowa Department of Natural Resources when issuing flood plain development permits. If different design discharges are proposed, prior approval from the DNR is required. When a project is located outside the detailed area of an FIS but could impact flood elevations or flood prone properties of an FIS community, the FIS information should be used for analysis.

  It should be noted that when a project involves development within a regulatory floodway (including bridge piers), the analysis must show that the project will not cause an increase in the 100 year flood elevation. If a “no rise” condition cannot be obtained when encroaching upon a regulatory floodway, the designer may need to apply to FEMA for revisions to the FIS by means of a Conditional Letter of Map Revision (CLOMR). After a CLOMR is issued and construction is completed a Letter of Map Revision (LOMR) is obtained by submitting as-built plans.

  Information from an FIS, if available, is preferred over other sources. The designer should check the FEMA website below to determine the current status of a community’s FIS:

  http://msc.fema.gov/webapp/wcs/stores/servlet/StoreCatalogDisplay?storeId=10001&catalogId=10001&langId=-1&userType=G

  ~~The designer may obtain a current list of FISs from the Flood Plain Permits Section of the Iowa DNR. A current list is available as Appendix A to Instructional Memorandum to County Engineers 3.131 on the Iowa DOT web site at the following address.~~

  ~~http://www.iowadot.gov/local_systems/publications/county_im/3_131/im_3_131.pdf~~

  Projects located in communities that are mapped by the National Flood Insurance Program as flood prone but do not show the 100-year flood elevation are not subject to the same requirements as a project located in a detailed FIS area. If a community does not have an adopted floodway or established base (100 year) flood elevations, it may be possible to construct a structure smaller than the existing structure as long as the upstream damage potential is low. Sound engineering judgment should be used when downsizing an existing structure.

- **U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers stream gage information**

  Stream gage information is available from the USGS and U.S. Army Corps of Engineers for many sites in Iowa. If the drainage area at the project site is within 50% of the drainage area of the gage, the gage discharges should be used and transferred to the project site per the method specified in USGS WRIR 00-4233. If 25 years or more of stream gage data is available, the area-weighted estimate for ungaged sites on gaged streams is preferred over the regression-weighted estimate. Stream gage information may be obtained from the USGS in Iowa web site, the U.S. Army Corps of Engineers web site, or from the USGS WRIR 00-4233 publication.

  http://ia.water.usgs.gov

  http://www.mvr.usace.army.mil

- **USGS WRIR 87-4132 and USGS WRIR 00-4233 regression equations**

  If the project site is not located in a detailed FIS or within 50% of the drainage area of a gage, the USGS regression equations should be used to estimate peak discharges. The Iowa DOT currently recommends that the USGS 87-4132 report be utilized for projects that have drainage areas between 2 and 20 square miles. If USGS Report 87-4132 is used to determine Q50, see the commentary for a chart to estimate Q500. For drainage areas greater than 20 but less than 50 square miles, the Iowa DOT recommends that both the USGS 87-4132 and 00-4233 reports be used for estimating the design discharges and engineering judgment (possibly averaging both methods) be utilized for determining the peak discharges. If the drainage area is greater than 50 square miles, the Iowa DOT recommends using the USGS 00-4233 report.

The USGS 00-4233 report utilizes one-variable equations for each of the three regions defined for the state. Two sets of equations are presented for Regions 2 and 3. The one-variable equations using only drainage area are considered easy for users to apply. However, the predictive accuracies of the multi-variable equations are better and therefore, the multi-variable equations should be used over the one-variable equations.

The Main-Channel Slope (MCS) variable is used for the flood-frequency estimation equations for Region 2 and Region 3. The USGS WRIR 03-4120, "Main-Channel Slopes of Selected Streams in Iowa for Estimation of Flood-Frequency Discharges" was published to provide a graphical representation of the MCS curves for 138 selected streams in Iowa with drainage areas greater than 100 square miles. The MCS values determined from the curves can be used in regression equations for estimating flood-frequency discharges for ungaged stream sites in Iowa.

- **~~Corps of Engineers, Iowa DNR, and~~ USGS flood reports**

  ~~Miscellaneous~~ Open file flood reports by the ~~Corps of Engineers, the Iowa DNR, and the~~ USGS have been developed and can be valuable supplemental information when evaluating discharges and water surface elevations. The reports are listed and, in some cases, available for download as follows.

  - ~~Corps of Engineers and Iowa DNR studies~~
  - ~~USGS flood reports studies~~

  http://ia.water.usgs.gov/pubs/iowa.publications.html

  http://ia.water.usgs.gov/projects/profiles

3.2.2.2 Hydraulics

Once the peak discharges are determined for design, the structure must be analyzed to determine the hydraulic capacity or conveyance of the bridge waterway opening. Bridge hydraulics (freeboard and backwater) can be analyzed by utilizing various hydraulic programs such as HEC-2 or HEC-RAS, which are available from the Corps of Engineers or other sources; the Iowa DOT Bridge Backwater program based on the publication *Hydraulics of Bridge Waterways, HDS 1*; or WSPRO, which is available from FHWA. The designer should be aware of the assumptions and limitations for using the methodology in any hydraulic analysis program.

- **HEC-2 or HEC-RAS analysis**

  When a bridge is located within a detailed Flood Insurance Study (FIS) area, or the upstream flood plain has a high damage potential (such as a residence or business located in the upstream flood plain), the designer should perform a HEC-2 or HEC-RAS analysis to determine the impacts on flood elevations.

- **Iowa DOT Bridge Backwater program analysis**

  For bridges located in a rural area where the flood plain has a low damage potential, the designer may use the Iowa DOT Bridge Backwater program to analyze backwater and freeboard provided the conditions listed below are met.

  (1) The channel is relatively straight.
  (2) The floodplain cross section is fairly uniform.
  (3) The stream slope is approximately constant.
  (4) The flow is free to contract and expand.
  (5) There is no appreciable scour hole in the bed at the constriction.
  (6) The flow is in the sub critical range (Type I, non-pressure flow)

- **WSPRO analysis**

  For bridges located in a rural area where the flood plain has a low damage potential, the designer may use WSPRO program to analyze backwater and freeboard.

3.2.2.3 Backwater

Bridge backwater is caused by the encroachment of the road embankment onto the floodplain which constricts flood flows through the bridge opening. This constriction causes an increase in the normal stage (flood elevation without a bridge and roadgrade in place). The maximum backwater typically occurs one or two bridge lengths upstream.

Iowa DNR backwater criteria are listed in Table 3.2.10.1-2. In general, bridges should be designed to meet the backwater criteria even when a project does not require Iowa DNR approval. Variances to the backwater criteria can be obtained when it is not economical to meet the backwater criteria and when flowage easements are obtained for low damage potential areas.

Manning’s Equation is used to determine normal depth and a stage-discharge relationship (rating curve) for analyzing bridges. Typical roughness coefficients for the equation are given in Table 3.2.2.3.

Table 3.2.2.3. Manning's Roughness Coefficients for natural stream valleys (n-coefficients)

Description	**Detailed Description**	**Manning's Coefficient**
Channel, small to medium drainage areas	Irregular section, meandering channel, rocky or rough bottom, medium to heavy growth on bank and side slopes	0.04-0.05
	Uniform section, relatively straight, smooth earthen bottom, medium to light growth on bank and side slopes	0.03-0.04
Channel, large drainage area	---	0.025-0.35
Overbank flood plain, pasture land	No brush or trees	0.05-0.07
	Light brush and trees	0.06-0.08
Overbank flood plain, crop land	---	0.07-0.09
Overbank flood plain, brush and trees	Heavy weeds, scattered brush	0.08-0.10
	Medium to dense brush and trees	0.09-0.12
	Dense brush and trees	0.10-0.15
	Heavy stand of timber, a few downed trees, little undergrowth	0.07-0.10

Table note:

The table is from the Iowa DNR's Bridge Review Checklist at the following Internet address:

http://www.iowadnr.com/water/floodplain/files/bridgereviewformchecklist.pdf

3.2.2.4 Freeboard

Freeboard is the vertical clearance measured between the bottom of the superstructure and the 50-year flood elevation not including backwater. Typically this clearance is measured at the middle of the channel.

The purpose of freeboard is to provide adequate clearance for passage of debris and ice during high flows and to reduce the potential of superstructure submergence. Debris and ice jams can create horizontal and buoyant forces on the bridge superstructure and can reduce the bridge waterway opening resulting in increased velocity, scour, and upstream flood levels. When hydraulic modeling predicts that a span in a pretensioned prestressed concrete beam (PPCB) bridge will be inundated by the 100-year or lesser floods, the designer should recommend that beams in the span be vented to prevent buoyancy forces. (See BDM 5.4.2.4.2 for beam vent details.) The designer also should recommend venting a steel superstructure with integral abutments that will be inundated from abutment to abutment by the 100-year or lesser floods [BDM 5.5.2.4.2].

For streams draining more than 100 square miles (259 square kilometers) in rural (unincorporated) areas and for streams draining more than 2 square miles (5.18 square kilometers) in urban (incorporated) areas, the required Iowa DNR clearance between a 50-year flood and the low superstructure is 3.0 feet (910 mm) of freeboard. For streams draining less than 100 square miles (259 square kilometers) in rural areas and streams draining less than 2 square miles (5.18 square kilometers) in urban areas, no Iowa DNR permit is needed, so freeboard of 3.0 feet (910 mm) is not required but still is desirable.

Occasionally, a variance to the Iowa DNR freeboard criteria can be requested where one or more of the following conditions are present:

- The bridge is a floodplain overflow structure,
- Ice or debris is not expected to be a problem,
- Roadgrade overflow readily provides relief in the event the bridge opening is obstructed, or
- Raising an existing grade will result in excessive costs or damages, as in heavily developed urban areas.

3.2.2.5 Road grade overflow

New primary road profile grades generally should be designed to ensure that the 100-year flood elevation is not greater than the outside edge of shoulder. However, the designer should recognize that if the road grade is much higher, road grade overflow will not serve as a relief valve for the bridge during an extreme flood.

Changes to existing primary road profile grades on bridge replacement projects also need careful consideration. The designer should ensure that raising profile grades in areas with a history of roadway overtopping does not have a negative impact to adjacent property owners.

Coordination of the road grades with the Office of Design may be required.

3.2.2.6 Streambank protection

Streambank erosion is a natural process in which the stream adjusts to changing conditions within its channel and watershed. The main factors contributing to streambank erosion are the velocity of water, angle of attack, soil type, lack of vegetation, and changes in land use.

When stream velocities exceed 8 to 10 feet per second (2.4 to 3.0 meters per second), riprap may be considered. Past aerial photos should be examined to determine an approximate rate of erosion.

There are many streambank stabilization practices used by the engineering profession. A detailed description of the different methods is beyond the scope of these guidelines. However, because 75% of the streambank failures are caused by toe scour, a common design practice for bank protection with riprap is to provide adequate protection at the toe of the bank: a minimum 6-foot (1.830 m) from the toe or to the maximum scour elevation. The riprap should be a minimum 2-foot (600-mm) thick layer of Class E Revetment [IDOT SS 2507.03]. The bank slope generally should be 2~~.0~~ horizontal to 1 vertical.

As a general rule, any streambank protection design should not extend more than 25% of the width of the eroded channel, which includes the sandbar. The streambank protection design should be sufficiently keyed into the bank to prevent undercutting. For a bank toe protection example see the commentary for this article.

A good streambank stabilization resource is the Iowa DNR's manual *How to Control Streambank Erosion*. The manual may be downloaded from the following web site:

http://www.iowadnr.gov/water/stormwater/forms/streambank_man.pdf

3.2.2.7 Scour

Scour calculations should be made for all new and replacement bridges. The most common cause of bridge failure is from floods scouring bed material from bridge piers and abutments. Bridge scour is the engineering term for the movement of soil caused by the erosive action of water. Bridge scour is a complex process and difficult to analyze but very important in terms of bridge safety and maintenance cost. For guidance on calculating bridge scour the office generally relies on the Federal Highway Administration (FHWA) publication *HEC-18 Evaluating Scour at Bridges, 4th Edition* and the recommendations and guidelines published in "Iowa DOT Bridge Scour Guidelines." See the commentary for this article. ~~{Guidance will be added to the commentary for this article in the future.}~~

The effects of scour should involve a multidisciplinary review of hydraulic, geotechnical, and structural engineers to assess the stability of a structure.

"Iowa DOT Bridge Scour Guidelines" is derived from *HEC-18*. The main difference between the FHWA publication and the Iowa DOT methodology is the way pier scour is calculated. For most cases pier scour in Iowa has been calculated using the research performed by Laursen under “Iowa Highway Research Board Bulletin No. 4, Scour Around Bridge Piers and Abutments.” *HEC-18* recommends the Colorado State University (CSU) equation for calculating pier scour. The Laursen equations and the CSU method give comparable results.

3.2.2.7.1 Types

There are two types of bridge scour: general or contraction scour and local scour.

- General or contraction scour is the decrease in streambed elevation due to encroachment of the road embankment onto the flood plain causing a contraction of flood flows, and
- Local scour is the loss of material around piers, abutments, wing dikes, and embankments.

There are two conditions for contraction and local scour: clear water and live-bed.

- Clear water scour occurs when there is little to no movement of the bed material of the stream upstream of the crossing. Typical situations include most overflow bridges without a defined channel, coarse bed material streams that could be found in northeast Iowa, ~~and~~ flat gradient streams during low flow, and bridges over main channels with a significant overbank length.
- Live-bed scour occurs when velocities are high enough to move the bed material upstream of the crossing. Most Iowa streams experience live-bed scour since they consist of sands and silts.

The designer should calculate the individual estimates of contraction, pier, and abutment scour. The designer should also consider long-term degradation when determining the total contraction scour depth. Local scour should be added below the contraction scour at each pier and abutment for evaluation. The designer should also apply engineering judgment when comparing results obtained from scour computations with available hydrologic and hydraulic data to achieve a reasonable and prudent design.

3.2.2.7.2 Design conditions

The design scour is determined for the 100-year or lesser flood, depending on which results in the most severe scour conditions. Usually the overtopping flood results in the worst scour, so evaluate this discharge if it is less than the 100-year flood. This scour depth is used by the final designer to check pile capacity and stability using load factors for the strength limit state.

The check scour is based on the occurrence of a 500-year or lesser flood, depending on which results in the most severe scour conditions. Bridge foundations will be evaluated by the final designer to ensure that they will not fail at the extreme event limit state due to the check (maximum) scour.

The preliminary situation plan hydraulic data block and longitudinal section shall show the design and check scour elevations.

3.2.2.7.3 Evaluating existing structures

When evaluating an existing bridge for scour, the designer should be aware of the procedures to evaluate the structure by engineering judgment to determine if it is scour-safe. A “Bridge Scour Stability Worksheet” and “Intermediate Scour Assessment Procedures” evaluation should be performed before proceeding with a calculated *HEC-18* scour analysis. This may significantly reduce the cost of analyzing structures for scour that could be considered scour-safe.

The “Bridge Scour Stability Worksheet” was developed in the early 1990s to assess structures based on the type of structure, observed conditions, and stream geomorphics. The structures were considered stable or scour-critical based on the point total determined from the worksheet.~~{A copy of the worksheet will be added to the commentary for this article in the future.}~~

The “Intermediate Scour Assessment Procedures” were developed in 1997 to provide additional assessment of existing structures that have not been evaluated for scour. A flowchart was developed to assess those bridges that could be considered scour-safe. ~~{A copy of the flowchart will be included in the commentary for this article in the future.}~~

If the structure is not determined to be scour-safe after assessment by the “Bridge Scour Stability Worksheet” or the “Intermediate Scour Assessment Procedure,” a full computational analysis (*HEC-18*) must be performed.

3.2.2.7.4 Depth estimates

{Text for this article will be added in the future.}

3.2.2.7.5 Countermeasures

{Text for this article will be added in the future.}

3.2.2.7.5.1 Riprap at abutments

{Text for this article will be added in the future.}

3.2.2.7.5.2 Riprap at piers

{Text for this article will be added in the future.}

3.2.2.7.5.3 Wing dikes

~~{Text for this article will be added in the future.}~~The use of wing dikes (also called spur dikes or guide banks) shall be considered at any bridge site that has appreciable overbank discharge (25% or more of the total Q). Wing dikes help minimize backwater and scour effects. See the commentary for a table on selecting appropriate lengths of wing dikes and the Office of Design’s manual [OD DM RL-3] for construction details. The riprap should typically be extended through the end of the wing dike.

3.2.2.7.6 Coding

{Text for this article will be added in the future.}